melt. The focal point is, as a rule, thereby clearly smaller than the object to be irradiated, i.e. the radiant flux density to be used decreases from the focal point to the object at approximately the square of the distance. For reasons of cooling technology, the radiation capacity of such radiation emitters is limited to a few kW, typically about 6 kW. Because of these two factors the specific dose rate of such a configuration is greatly limited.

The U.S. patent application US 2002/0021068 discloses a device for generating electromagnetic radiation. The walling of the tube serves at the same time as cathode, and is transparent for the X-ray radiation. In an embodiment variant, the cathode possesses a thin electron-emitting layer. The X rays emerging from the target pass through the cathode, and are radiated to the outside.

The U.S. patent application US 2001/0019601 describes a cold cathode, which consists of nano tubes.

In the miniaturized X-ray tube described in the patent document U.S. 5,729,583 the anode of the X-ray tube is designed at the same time as walling of the X-ray tube head. The X-ray radiation is emitted directly to the outside.

The cathode in the X-ray tube disclosed in the U.S. American patent application U.S. 2003/0002627 is a carbon nano tube, or possesses a layer of a similar substance.

The American patent U.S. 6,477,233 discloses a miniaturized X-ray tube in which the two electrodes are disposed opposite each other inside a cavity formed by the walling.

The German patent document DE 198 32 032 discloses an X-ray tube with a thermal cathode, which is nevertheless suitable for use in catheters for treatment of blood vessels. In this X-ray tube, the cathode is designed as a solid cylinder.

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Thanks to its very minimal size, a miniaturized X-ray tube such as in the international patent application WO 99/62589 can be used to treat tissue inside the human body. One of the embodiment variants discloses an X-ray tube in which the anode is designed as hollow cylinder.

The French patent application FR 2 574 592 describes a back scatter X-ray tube by means of which X-ray radiation of very high power and very short duration can be generated. For this purpose the described X-ray tube possesses a focusing mechanism for the electrons accelerated to the target.

The patent applications US 2003/0063707, US 2004/0008818 as well as the patent document U.S. 4,670,894 disclose X-ray tubes having at least partially a cylindrical shape.

It is an object of this invention to propose a new X-ray tube for high dose rates and a corresponding method for generating high dose rates with X-ray tubes which do not have the drawbacks described above. In particular, an X-ray emitter should be proposed which enables a dose rate many times higher than conventional X-ray emitters. Likewise the percentage of usable energy converted into γ-rays should be increased, and a more uniform distribution of the γ-rays with respect to the surface to be irradiated and the depth of the material should be obtained.

This object is achieved according to the invention in particular through the elements of the independent claims. Further advantageous embodiments follow moreover from the dependent claims and from the description.

In particular, these object are achieved according to the invention in that in the X-ray tube an anode and a cathode are disposed opposite each other in a vacuumized internal chamber, electrons being able to be accelerated to the anode by means of impressible high voltage, the cathode comprising a thin

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layer or coating of an electron-emitting material, and the cathode comprising a substrate substantially transparent for X-ray radiation, the X-ray tube being designed as anode hollow cylinder with a coaxial cathode hollow cylinder inside. This embodiment variant has the advantage, among others, that e.g. the material to be irradiated can be put inside the cathode hollow cylinder. This ensures an evenly high and homogeneous irradiation of the object from all sides (4π), which would hardly be possible otherwise. This embodiment variant can be suitable in particular for sterilization with continuous conveyance of the material to be sterilized, and thus for high throughput.

In another embodiment variant, the cathode can thereby close the vacuumized internal chamber toward the outside, for example. For conversion of the electrons into X-ray radiation, the anode can comprise in particular e.g. gold and/or molybdenum and/or tungsten and/or a compound of the metals. An advantage of the invention is, among others, that the cooling of the anode can be optimized since the anode does not have to be selected to be transparent for X-ray radiation, compared with a design alternative with an anode transparent for X rays.

In an embodiment variant, the cathode comprises a thermionic emitter. This embodiment variant has the advantage, among others, that thermionic emitters are state of the art in X-ray tubes, and distinguish themselves through high stability and long service life. The emitters can thereby consist of heated tungsten wires which are either strung parallel or are welded to a mesh grid. Emitters of barium hexaboride or so-called heated dispenser cathodes based on barium mixed oxides can also be used, however, which have a very high emission current density, and can be arranged in groups in order to achieve large-area cathodes.

In another embodiment variant, the cathode comprises a cold emitter, in particular with metal tips and/or carbon tips and/or carbon nano tubes. This embodiment variant has the advantage, among others, that the emitters can be installed in a thin layer on a substrate in a large-area way, and

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can thereby result in little to no heat loss in operation. A cooling can thereby be omitted, and a high transmission for X-rays can be ensured for the cathode. These cold emitters are preferably combined with an extraction grid with which the current density can be controlled.

In another embodiment variant, the cathode comprises a substrate for the thermionic emitters or the cold emitters of a material especially penetrable for X rays, such as e.g. beryllium, aluminum or in particular pyrolytic graphite. The substrate can thereby be designed such that it serves at the same time as the closure of the vacuum vessel.

It should be stated here that, besides the method according to the invention, this invention also relates to a device for carrying out this method as well as to a method for producing such a device.

Embodiment variants of the present invention will be described in the following with reference to examples. The examples of the embodiments are illustrated by the following enclosed figures:

Figure 1 shows a block diagram illustrating schematically an X-ray tube 10 of the state of the art. Electrons e^- are thereby emitted from a cathode 20, and X-rays γ radiated from an anode 30 through a window 301.

Figure 2 shows a block diagram, illustrating schematically the architecture of one embodiment variant of an X-ray tube 11 according to the invention. Electrons e^- are thereby emitted by a transmission cathode 21, and X rays γ radiated from an anode 31, the cathode 21 forming the cylinder barrel of a cylindrical tube core, and closing the vacuumized internal chamber 41.

Figure 3 shows a block diagram, illustrating schematically the architecture of an embodiment variant of an X-ray tube 12 according to the

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According to the invention, the vacuumized internal chamber 41/42 of the X-ray tube 11/12 can be closed off by the transmission cathode 21/22 toward the outside, or respectively toward the inside, for example. The radiation goes through the transmission cathode 21/22, and behind it hits the material to be irradiated. The anode 31/32 comprises a layer of a metal with a high atomic number, e.g. gold and/or molybdenum and/or tungsten and/or a compound of the metals, allowing an efficient conversion into X-ray radiation γ. The anode 31/32 further comprises a cooling for cooling the thermal energy being created. The anode 31/32 must be cooled since typically only about 1 % of the electric capacity is converted into X-ray radiation, and the rest must be given off as heat. The cooling can take place using water or with forced air. Through the configuration according to the invention, the entire radiation can be made use of in the outer half space. In contrast, in the conventional configuration, only about 10 % of the radiation can be used in the half space (with 50° angle of opening of the window). A second advantage is that the area irradiated by the electrons e^- is considerably larger in the design according to the invention than in the conventional configuration. Assuming an irradiated area (anode) of 20 x 20 cm^2 and a possible cooling capacity in this area of 200 W/cm^2, there results a possible total electrical power of 80 kW, in contrast to 6 kW with the conventional tube. That is a further increase by a factor of 10. A transmission cathode 21/22 possibly absorbs, however, more radiation than a Be window in a conventional tube, depending upon the design. The output radiation is can <sic.> be thereby reduced by about half, depending upon wavelength. A dose rate increased overall by a factor of 50 still nevertheless results from this on a area of about 20 x 20 cm^2, compared with the configuration with a conventional X-ray emitter. This increase in dosing capacity makes it possible, for example, to carry out sterilization with X rays in very short time periods.

Figure 1 shows schematically an architecture of such a conventional X-ray tube 10 of the state of the art. Electrons e^- are thereby emitted from an electron emitter, i.e. a cathode 20, as a rule a hot tungsten coil, are accelerated to a target through impressed high voltage, X rays γ being emitted from the target, i.e. from the anode 30, through a window 301. In other words, with the impingement of the electrons e^- on the target, X-ray radiation γ is generated at the thus arising focal spot. The X-ray radiation emerges into the outer space

through a window 301, and is used for irradiation purposes. Of the radiation generated on the target, only a small portion reaches the material to be irradiated. For reasons of geometry, the major part of the radiation is absorbed in the tube itself. For this reason, in order to irradiate the object completely, a particular irradiation spacing must be selected, depending upon the size of the object. In conventional configurations, typically, only about 10 % of the radiation can be used in the half space of the target surface. Figure 1 shows an emission window 301 with an opening of 50°.

Figure 2 shows schematically the architecture of one embodiment variant of an X-ray tube 11 according to the invention. Electrons e^- are thereby emitted from a transmission cathode 21, and X rays γ are emitted from an anode 31, the cathode 21 forming the cylinder barrel of a cylindrical tube core, and closing the vacuumized internal chamber 41. In other words, the X-ray tube 11 is designed as anode hollow cylinder 31 with a coaxial cathode hollow cylinder 21 inside. Anode 31 and cathode 21 can be achieved as described in more detail further above, for example. The electrons e^- are accelerated from the transmission cathode 21 to the anode 31, and generate there X-ray radiation γ. The X-ray radiation γ penetrates the cathode 21 transparent for X-ray radiation γ. A uniform and very high 4π- gamma radiation, for example, can thus be achieved inside the cathode hollow cylinder 21. The material to be irradiated can be placed inside the cathode hollow cylinder 31. This ensures an even irradiation of the object from all sides, which would hardly be possible otherwise. This can be especially expedient for sterilization. It can be said that this embodiment variant is particularly suitable for sterilization with continuous conveyance of the material to be sterilized, and thereby for high throughput. A further advantage of this embodiment example is that since the anode does not have to be selected to be transparent for X-ray radiation, the cooling of the anode can be optimized compared with an embodiment variant with an anode transparent for X rays.

Figure 3 shows schematically an architecture of a section of an X-ray tube 12 according to the invention. Electrons e^- are thereby emitted from thermionic or cold emitters 72 in a transmission cathode 22, and X rays γ are radiated from an anode 32, the cathode 22 closing the

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Claims

1. An X-ray tube (11/12) for high dose rates, in which an anode (31/32) and a cathode (21/22) are disposed opposite each other in a vacuumized internal chamber (41/42), electrons (e^-) being able to be accelerated to the anode by means of impressible high voltage, the cathode (21/22) comprising a thin layer of an electron (e^-) -emitting material, and the cathode (21/22) comprising a substrate substantially transparent for X-ray radiation (γ), wherein

the X-ray tube (11) is designed as an anode hollow cylinder (21) with a coaxial cathode hollow cylinder (31) inside.

2. The X-ray tube (11/12) according to claim 1, wherein the cathode (21/22) closes the vacuumized internal chamber (41/42) toward the outside.

3. The X-ray tube (11/12) according to one of the claims 1 or 2, wherein the anode (31/32) comprises gold and/or molybdenum and/or tungsten and/or a compound of the metals, for conversion of the electrons (e^-) into X-ray radiation (γ).

4. The X-ray tube (11/12) according to one of the claims 1 to 3, wherein the cathode (21/22) comprises a thermionic emitter (72).

5. The X-ray tube (11/12) according to one of the claims 1 to 3, wherein the cathode (21/22) comprises a cold emitter (72).

6. The X-ray tube (11/12) according to claim 5, wherein the cold emitter comprises metal tips and/or graphite tips and/or carbon nano tubes.

7. The X-ray tube (12) according to one of the claims 1 to 6, wherein

the anode (32) is designed as a round or angular surface, the anode (32) being irradiated by a laminar or reticulate emitter (72) in a cathode (22) substantially transparent for X-ray radiation (γ).

8. A method for generating high dose rates with X-ray tubes (11/12), in which an anode (31/32) and a cathode (21/22) are disposed opposite each other in a vacuumized internal chamber (41/42), electrons (e^-) being accelerated to the anode (31/32) by means of impressible high voltage, a substrate substantially transparent for X-ray radiation (γ) being used in the cathode (21/22), and a thin layer or coating of an electron (e^-)-emitting material being applied to the substrate wherein

used as the anode is an anode hollow cylinder (21) with a coaxial cathode hollow cylinder (31) inside.

9. The method according to claim 8, wherein the cathode (21/22) closes the vacuumized internal chamber (41/42) toward the outside.

10. The method according to one of the claims 8 or 9, wherein gold and/or molybdenum and/or tungsten and/or a compound of the metals is used for conversion of the electrons (e^-) into X-ray radiation (γ).

11. The method according to one of the claims 8 to 10, wherein a thermionic emitter is used in the cathode (21/22).

12. The method according to one of the claims 8 to 11, wherein a cold emitter is used in the cathode (21/22).

13. The method according to claim 12, wherein metal tips and/or graphite tips and/or carbon nano tubes are used for the cold emitter.

14. The method according to one of the claims 8 to 13, wherein the

anode (32) is designed as a round or angular surface, the anode (32) being irradiated by an emitter (72), of laminar or reticulate design, in a cathode (22) substantially transparent for X-ray radiation (γ).

15. A method for producing an X-ray tube (11/12) for high dose rates, in which an anode (31/32) and a cathode (21/22) are disposed opposite each other in a vacuumized internal chamber (41/42), electrons (e^-) being accelerated to the anode (31/32) by means of impressible high voltage, a substrate substantially transparent for X-ray radiation (γ) being used in the cathode (21/22), and a thin layer or coating of an electron (e^-)-emitting material being applied to the substrate wherein

the X-ray tube (11) is designed as an anode hollow cylinder (21) with a coaxial cathode hollow cylinder (31) inside.

16. The method according to claim 15, wherein the cathode (31/32) closes the vacuumized internal chamber (41/42) toward the outside.

Claims

1. An X-ray tube (11/12) for high dose rates, in which an anode (31/32) and a cathode (21/22) are disposed opposite each other in a vacuumized internal chamber (41/42), electrons (e^-) being able to be accelerated to the anode by means of impressible high voltage, the cathode (21/22) comprising a thin layer of an electron (e^-) -emitting material, and the cathode (21/22) comprising a substrate substantially transparent for X-ray radiation (γ), wherein

the X-ray tube (11) is designed as an anode hollow cylinder (21) with a coaxial cathode hollow cylinder (31) inside.

2. The X-ray tube (11/12) according to claim 1, wherein the cathode (21/22) closes the vacuumized internal chamber (41/42) toward the outside.

3. The X-ray tube (11/12) according to one of the claims 1 or 2, wherein the anode (31/32) comprises gold and/or molybdenum and/or tungsten and/or a compound of the metals, for conversion of the electrons (e^-) into X-ray radiation (γ).

4. The X-ray tube (11/12) according to one of the claims 1 to 3, wherein the cathode (21/22) comprises a thermionic emitter (72).

5. The X-ray tube (11/12) according to one of the claims 1 to 3, wherein the cathode (21/22) comprises a cold emitter (72).

6. The X-ray tube (11/12) according to claim 5, wherein the cold emitter comprises metal tips and/or graphite tips and/or carbon nano tubes.

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7. A method for generating high dose rates with X-ray tubes (11/12), in which an anode (31/32) and a cathode (21/22) are disposed opposite each other in a vacuumized internal chamber (41/42), electrons (e^-) being accelerated to the anode (31/32) by means of impressible high voltage, a substrate substantially transparent for X-ray radiation (γ) being used in the cathode (21/22), and a thin layer or coating of an electron (e^-)-emitting material being applied to the substrate wherein

used as the anode is an anode hollow cylinder (21) with a coaxial cathode hollow cylinder (31) inside.

8. The method according to claim 7, wherein the cathode (21/22) closes the vacuumized internal chamber (41/42) toward the outside.

9. The method according to one of the claims 7 or 8, wherein gold and/or molybdenum and/or tungsten and/or a compound of the metals is used for conversion of the electrons (e^-) into X-ray radiation (γ).

10. The method according to one of the claims 7 to 9, wherein a thermionic emitter is used in the cathode (21/22).

11. The method according to one of the claims 7 to 10, wherein a cold emitter is used in the cathode (21/22).

12. The method according to claim 11, wherein metal tips and/or graphite tips and/or carbon nano tubes are used for the cold emitter.

13. A method for producing an X-ray tube (11/12) for high dose rates, in which an anode (31/32) and a cathode (21/22) are disposed opposite each other in a vacuumized internal chamber (41/42), electrons (e^-) being

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accelerated to the anode (31/32) by means of impressible high voltage, a substrate substantially transparent for X-ray radiation (γ) being used in the cathode (21/22), and a thin layer or coating of an electron (e^-)-emitting material being applied to the substrate wherein

the X-ray tube (11) is designed as an anode hollow cylinder (21) with a coaxial cathode hollow cylinder (31) inside.

14. The method according to claim 13, wherein the cathode (31/32) closes the vacuumized internal chamber (41/42) toward the outside.